CHARACTERIZATION OF WHOLE-BODY VIBRATION FOR MONORAIL PASSENGER RIDE COMFORT

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This thesis is dedicated to my Parents

(Haji Ghulam Muhammad Jamali and Razia Begum)

&

My Wife

(Aisha Jamali)

My Daughters

(Sahiqa Naz & Amima Naz)

My Son

(Abdul Haseeb Jamali)

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ABSTRACT

Train travel has always been a major mode of public transport in developed countries. In the inner cities monorails are often used, which are operated at elevated rail or beam, the main advantage being traffic interactions can be minimized while maintaining its original landscape. Ride comfort is the basic requirement for every passenger in all kind of public transports. In monorail, vibration is considered as major factor of discomfort, it transmitted to human body, which contribute many health issues. The aim of this study was to evaluate the whole-body vibration transmission and the effects to the monorail passengers. There were total of twenty-four experiments conducted in a two-car train monorail on its complete line from Kuala Lumpur Sentral to Titiwangsa stations. Human vibration meter (HVM-100) with tri-axial accelerometer pad was used to measure the WBV of passengers and International Standards Organization (ISO) 2631-1: 1997 was used for analysis. The experimental results show that the daily vibration exposure 0.81 m/s^2 was higher than the action value 0.5 m/s^2 of the standard during peak operation and 0.82 m/s^2 during off-peak operation. The health effect was measured 9.90 $m/s^{1.75}$ during peak operation and 9.94 $m/s^{1.75}$ during off-peak operation; both values are observed in moderate health effect zone as per standard (8.5 $m/s^{1.75}$ to 17 $m/s^{1.75}$). Moreover, the passenger ride comfort was measured, it was found to be fairly-uncomfortable at rear bogie and not-uncomfortable at center of car. The statistical analysis has proven the significance of orientation, location and operating hours by significant value $p = 0.000$ (i.e. $p < \alpha$) with 29.5% of the variance has been accounted between groups. This provides justification to standardization of proper priority seating zone. The findings of this study can assist in the standard specification for seating design of monorail. The statistical analysis shows that all results are statistically significant for orientations, locations as well as operations.

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ABSTRAK

Di kebanyakan negara yang membangun, keretapi merupakan pilihan pengangkutan awam yang utama yang digunakan. Monorel yang dikendalikan di rel tinggi atau rasuk selalunya menjadi pilihan disebabkan ianya dapat meminimumkan interaksi trafik di samping mengekalkan lanskap asal. Keselesaan penumpang adalah keperluan asas bagi setiap penumpang dalam semua jenis pengangkutan awam. Untuk kes monorel, penghawa dingin dan reka bentuk tempat duduk, getaran juga dianggap sebagai faktor utama yang menyumbang kepada ketidakselesaan penumpang. Tujuan kajian ini adalah untuk menilai penghantaran getaran seluruh badan dan kesannya kepada penumpang monorel. Terdapat dua puluh empat eksperimen yang dijalankan di dua keretapi monorel di laluan lengkap dari Sentral Kuala Lumpur ke stesen Titiwangsa. Meter getaran manusia (HVM-100) dengan pad pecutan *tri-axial* digunakan untuk memantau WBV penumpang. Manakala untuk pengukuran dan analisis, Piawaian Pertubuhan Antarabangsa (ISO) 2631-1: 1997 telah digunakan didalam kajian ini. Keputusan eksperimen telah menunjukkan bahawa pendedahan getaran harian 0.81 m/s^2 adalah lebih tinggi daripada nilai piawaian tindakan iaitu 0.5 m/s^2 semasa operasi puncak dan 0.82 m/s^2 semasa operasi luar puncak. Kesan kesihatan juga telah diukur sebanyak 9.90 $m/s^{1.75}$ semasa operasi puncak dan 9.94 $m/s^{1.75}$ semasa operasi luar puncak; pemerhatian terhadap kedua-dua nilai ini telah dilakukan bagi zon kesan kesihatan yang sederhana mengikut piawaian yang ditetapkan (8.5 $m/s^{1.75}$ hingga 17 $m/s^{1.75}$). Selain itu, keselesaan penumpang semasa perjalanan juga telah diukur. Kajian mendapati penumpang kurang selesa pada *bogie* belakang dan tidak selesa di tengah-tengah untuk kedua-kedua kereta api pada waktu operasi. Dapatan kajian ini memberikan justifikasi kepada standard zon keutamaan yang sesuai dengan penumpang yang sensitif kepada getaran. Disamping itu, ia dapat membantu menentukan standard rekabentuk kedudukan kerusi dalam monorel. Analisis statistik juga menunjukkan bahawa semua dapatan kajian adalah signifikan secara statistik bagi orientasi, lokasi dan operasi.

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LIST OF ABBREVIATIONS

Amax	-	Maximum Acceleration
Amp	-	Peak Acceleration
ANOVA	-	Analysis of Variance
Arms	-	Root mean square Acceleration
BB	-	Bukit Bintang
Bg1SitDs	-	Bogie 1 Sitting Downstream
Bg1SitUs	-	Bogie 1 Sitting Upstream
Bg1StdDs	-	Bogie 1 Standing Downstream
Bg1StdUs	-	Bogie 1 Standing Upstream
Bg2SitDs	-	Bogie 2 Sitting Downstream
Bg2SitUs	-	Bogie 2 Sitting Upstream
Bg2StdDs	-	Bogie 2 Standing Downstream
Bg2StdUs	-	Bogie 2 Standing Upstream
Bg1Ds	-	Bogie 1 Downstream
Bg1Us	-	Bogie 1 Upstream
Bg2Ds	-	Bogie 2 Downstream
Bg2Us	-	Bogie 2 Upstream
CnDs	-	Center Downstream
CnUs	-	Center Upstream
BN	-	Bukit Nanas
Bogie 1	-	Front bogie
Bogie 2	-	Rear bogie
CF	-	Crest Factor
CK	-	Chow Kit
CnSitDs	-	Center Sitting Downstream
CnSitUs	-	Center Sitting Upstream
CnStdDs	-	Center Standing Downstream

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CnStdUs	-	Center Standing Upstream
D	-	Downstream
eVDV	-	Estimated Vibration Dose Value
HT	-	Hang Tuah
HVM	-	Human Vibration Meter
IB	-	Imbi
ISO	-	International Standard Organization
IST-test	-	Independent Sample T-test
KL	-	Kuala Lumpur
KLMS	-	Kuala Lumpur Monorail System
KLS	-	Kuala Lumpur Sentral
LBP	-	Lower Back Pain
LRT	-	Light-Rail Transit
ML	-	Maharajalela
MRT	-	Mass Rapid Transit
MSDV	-	Motion Sickness Dose Value
MT	-	Medan Tuanku
r.m.s	-	Root Mean Square
RC	-	Ride Comfort
RC	-	Raja Chulan
SEAT	-	Seat Effective Amplitude Transmissibility
TS	-	Tun Sumbhatan
TW	-	Titiwangsa
U	-	Upstream
VDV	-	Vibration Dose Value
WBV	-	Whole-body Vibration

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LIST OF PUBLICATIONS

JOURNAL ARTICLES:

1. **Analysis of WBV on standing and seated passengers during off-peak operation in KL monorail**
   Khalid Hasnan, Qadir Bakhsh, Aqeel Ahmed, Danish Ali, Ali Raza Jamali
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2. **Whole Body Vibration exposure on standing and seated passengers during peak operation in KL monorail**
   Khalid Hasnan, Qadir Bakhsh, Noor Aqilah, Aqeel Ahmed, Danish Ali, Ali Raza
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   Organized by: Malaysia Technical Scientist Association (MALTESAS)

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CHAPTER 1

INTRODUCTION

This chapter explains the background of study briefly, followed by problem statement and aim of the study. Based on the problem statement, the objective of the study was designed to overcome it. The scope of this study and significance are also discussed in this chapter. At the last, the layout of this thesis is described chapter by chapter.

1.1 Background

Many people face the whole-body vibration (WBV) in their occupational life, specially the drivers and passengers of various vehicles, such as trucks, cars, trains and buses (Demic, Lukic & Milic, 2002). Whenever, there is vibration transmission to whole body of human by means of the vibration source matting with the bottom back or feet of human is always considered as WBV (Sylvester, 2009).

When the drivers or passengers are seated on a fixed seat, the acceleration from the source is transmitted through seat to their body (Falou *et al.*, 2003). Among longitudinal and lateral vibrations, the vertical vibrations (in z-axis directions) are mainly affects the human body in case of WBV. These vertical vibrations are transmitted from the seat or floor to the buttocks and back of the persons along the vertebral axis through the seat pan and back (Cann, Salmoni & Eger, 2004). The continuous or long-term exposure to high amplitude WBV is strongly connected with the successive growth of lower back pain in human body (Limerick & Lynas, 2016).

Exposure to WBV causes a complex distribution of oscillatory motions and forces within the body. There can be large variations between subjects with respect to

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biological effects. WBV may cause sensations (e.g. discomfort or annoyance), influences human performance capability or present a health and safety risk (Pathological damage or Physiological change). The presence of oscillatory force with little motion may cause similar effects (ISO, 1997).

Usually, in vehicles the passengers while riding on uneven surfaces and in case of machines, the operators always exposed to WBV. Also, the human body posture plays an important role in the magnitude of vibration transmission to their body (Ismail *et al.,* 2010). In whole-body vibration the human body experienced with complex distribution of oscillatory waves and forces. It usually affects the human performance capability by discomfort or annoyance, influences a health and safety risk (ISO, 1997).

WBV can be described when the environment is undergoing motion and affect the whole portion of the body which is not local to any particular point of contact. It occurs when the body is supported on a vibrating surface. There are three principal possibilities: sitting on a vibrating seat, standing on a vibrating floor, or lying on a vibrating bed (Griffin, 1990). According to Sayed *et al.,* (2012) it was clear that the metro passengers are exposed to serious magnitudes of WBV. The WBV gained in human body is increased when the duration of vibration exposure and the total metro trips experienced by the subject enlarged. The exceeding of high vibration exposures over the allowable limits to the passengers, would cause many side effects that include lower back pain (LBP), headache, shoulder pain and emotional instability (Mcphee, Foster, & Long, 2001; ISO, 1997).

The exposure of vibration to human body has many sources: in all kind of vehicles, buildings, and from the operation of industrial machines (Morioka & Griffin, 2000). In case of various transportations, the contact of human body with the vibrating surfaces usually caused the transmission of whole-body vibration such as; seat for driver and passenger or vehicle floor or body (Park *et al.,* 2013). The human body posture has been found to be predominant and it influences the surface of contact with the vibrating medium (Harazin & Grzesik, 1998).

Demic *et al.,* (2002) states that the effects on humans of exposure to vibration at best may be discomfort and interference with activities; at worst may be injury or disease. Vertical acceleration called z axis vibration is the most common vibration in railway vehicles, which people are exposed (Goodall & Mei, 2006). An example of this is the vibration experienced when driving over potholes or when trotting on a horse. There is also lateral acceleration called y axis vibration, and longitudinal

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acceleration called x axis vibration are commonly experienced on rail vehicles. When the duration and dose of WBV increases in all occupational environments, usually it has directly impact on the increase in risk for injury (Yang & Yin, 2014).

1.2 Problem statement

The monorail considered as noiseless and more comfortable ride than the other trains or steel wheeled trains (Kennedy, 2010), because of rubber tires and elevated track interaction. This vibration transmission from source to the passengers would have many effects on passengers. As humans are very sensitive to shaking, shocks and sudden jerks and find that unpleasant. This train vibration always results the discomfort in ride. In one study Demic *et al.*, (2002) described that the train passengers are facing some problems such as uncomfortable in ride, which is caused by WBV. The amount of discomfort experienced varies with the frequency of the acceleration. Therefore, it is necessary to weigh the accelerations for a compound motion together and form a single number that used to compare the level of discomfort. Likewise, Kim *et al.*, (2009) also examined that vibration is generally considered to be the primary factor that influence ride comfort of passengers. Boyenzi & Betta (1994) investigated that there is always a complaint among the passengers of different vehicles about the development of musculoskeletal due to the excessive exposure to WBV due to uncooperative working postures.

Furthermore, the study described that the different level of vibration also affects the ride performance for passengers at different locations of railway vehicle. WBV tend to affect the human body which is mainly in vertical vibrations. These vibrations are transmitted to the buttocks and back of the occupant along the vertebral axis via the base and back of the seat (Falou *et al.*, 2003). The WBV usually cause health and safety risk such as; ride discomfort, badly disturb their performance, lower back pain, shoulder pain, nausea and other health conditions (Mcphee, Foster & Long, 2001; ISO, 1997). The ride quality of monorail is affected by a variety of factors, including vibrations, noise, seat design, and centrifugal forces while curving. When the train is braking and cornering, the body produces a booming resonance, and the humans normally experience an uncomfortable ride (Kim *et al.*, 2009).

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APPENDIX A

ACCELERATION GRAPHS FOR PEAK OPERATION

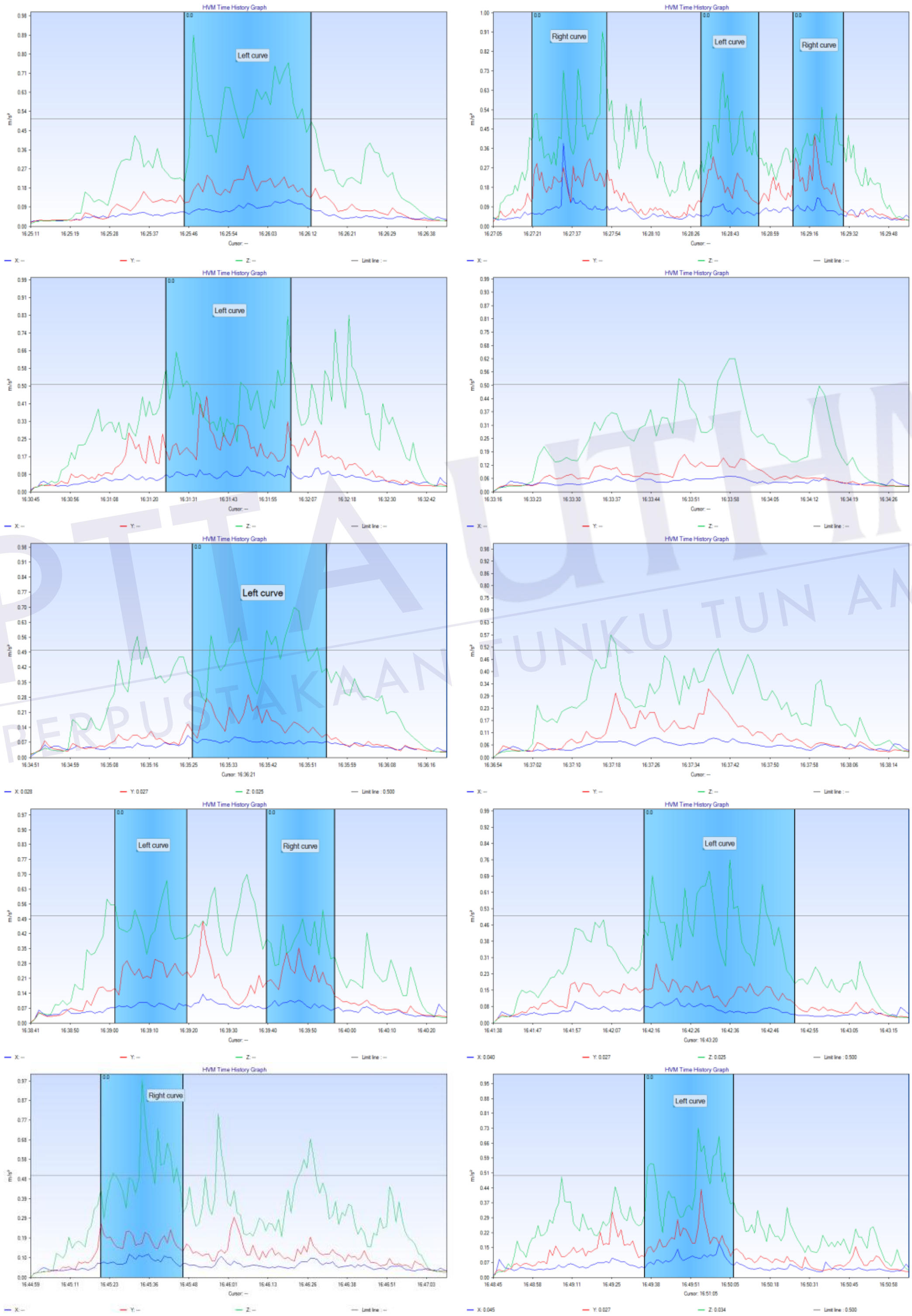

Figure A.1 Acceleration graph at bogie 1 during standing downstream trip

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